Appendix I

Anchoring and Placement of Large Woody Debris

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Appendix I

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Ultimately, the Aquatic Habitat Guidelines program intends to offer one complete set of appendices that apply to all guidelines in the series. Until then, readers should be aware that the appendices in this guideline may be revised and expanded over time.

The use of large woody debris can play a crucial role when used by itself, but also when used in concert with or incorporated into other techniques. Large woody debris can enhance the effectiveness of bank-protection treatments while mitigating the treatments' negative effects on fish habitat. The use of rock and other bank-hardening materials in streambank-protection projects often results in the loss of fish habitat. Rock revetments create smooth banks, resulting in high near-bank velocities, loss of cover and a reduction in structural and hydraulic complexity. Structural complexity and hydraulic complexity created by large woody debris are important components of good fish habitat. It has been found that fish use increases when large woody debris is included in rock revetment projects.[1] Placement of large woody debris is, therefore, considered an ideal form of mitigation. As an added benefit, some sites have shown that wood added for habitat restoration performs a bank-protection function as well. Downstream velocities are decreased and energy is dissipated in the form of turbulence around the large woody debris, encouraging deposition and reducing near-bank scour, while enhancing complex rearing and holding habitat for salmonids at low and high flows.

Properly placed and anchored large woody debris, when used as part of a bank-protection treatment, can assist in providing reliable bank protection as well as enhance the structural and hydraulic complexity of the channel. In contrast, poorly placed or improperly anchored large woody debris has a high probability of becoming dislodged under high flows, resulting in a failure of the project objectives and potential impacts to downstream infrastructure. Large wood should be placed in locations and configurations where it could be expected to occur naturally to increase its reliability in providing fish and wildlife habitat.

APPLICATION

Large woody debris is used in streambank-protection treatments for three primary reasons:

1. to assist in providing bank protection,
2. to enhance fish habitat, and
3. to accelerate floodplain and riparian structure in recovering alluvial channels.

Large woody debris can be keyed into the streambank, partially embedded into the channel, pieced together to form channel-spanning, midchannel or lateral jams in large rivers, and placed in floodplains to provide roughness in channels that are laterally migrating following incision. Depending upon the size of the large woody debris relative to the channel, its placement may constrict the channel by creating roughness, blocking a portion of the channel and potentially aggrade upstream channel segments. The energy dissipation associated with large woody debris creates a scour pool in erodible bed material, which in turn creates cover habitat. Scour-pool characteristics are somewhat predictable and are influenced by the shape, size and orientation of large woody debris. Large wood on floodplains provides high-flow refuge habitat for salmonids. Floodplain wood also enhances fine-sediment deposition required to establish riparian vegetation on new bar forms in alluvial streams.

There are many ways to configure large wood to accomplish a variety of objectives. When applying wood to any situation, a good understanding of the site's hydrology, hydraulics and geomorphology is important. The ability to obtain and match the wood size with the objectives and stream power are key to a successful project using large wood. In larger streams, it can be difficult to collect the size of wood needed to naturally function and accomplish habitat goals and objectives. It is possible to overcome this using smaller, undersized wood that is creatively pieced together and secured to emulate the geomorphic and hydraulic influence that a larger, old-growth piece could have in a given location. In these situations, effective placement must consider stability, function, longevity, risk and safety.

The natural effectiveness of large woody debris is largely dependent on channel type. Some streams are too steep, too confined or have too high a bedload volume to respond to the placement of large woody debris. Some streams and stream reaches have a naturally smaller large-wood influence than others. The ability of the adjacent riparian areas to grow trees that can influence channel morphology when delivered to the stream plays a key role in where large wood will most likely create habitat in a given watershed. This not only changes between watersheds but is also a continuum as one moves from the top to the bottom of individual watersheds. Geology and watershed scale processes sort and establish different roles for wood, depending upon wood size and location in the watershed. For example, a large tree branch that collects gravel in a headwater tributary would be part of the debris floating down and captured by a log jam further downstream. Understanding the basic processes and geography of wood location within individual watersheds are concepts that should be considered when installing or reintroducing large wood to streams and riparian areas.

The selection of correctly sized large woody debris is fundamental to the success of a project. Wood placed in a channel that the stream cannot move can have a dramatic effect on channel shape, grade and orientation. In these cases, the wood behaves more like rock. There are many positive but also potentially negative consequences of using wood so large that a small or medium stream cannot move it. This is especially true in alluvial channels and in areas where infrastructure is present. It is important to understand sediment transport, streambank stability and the upstream flood impacts when aggressively using large wood in these situations.

Conversely, undersized large woody debris placed in a channel can have little or no effect in terms of bank protection or fish habitat. It is also important to accurately assess the wood volume needed to realistically accomplish the desired objectives. Wood volumes required to restore natural function and habitat in larger streams are often underestimated. This is especially true in degraded alluvial environments where substantial amounts of wood placements are required in flood-prone areas outside of the low-flow channel.

In some small valley or meadow streams, and in a few areas in eastern Washington, wood is not a natural component of channel systems. While the addition of wood may still provide habitat and mitigation value, it should be acknowledged that in such systems wood may be less appropriate.

PLACEMENT CONSIDERATIONS

The design of large-woody-debris projects must be carefully considered to ensure their success as both bank protection and habitat. Unfortunately, the failures of some bank-protection projects involving large woody debris for habitat mitigation have been wrongly attributed to the wood rather than to the designer for not creating an integrated project. As designers become more adept at incorporating large woody debris into streambank-protection projects, its effectiveness and frequency of use will increase. *Figure I-1* (at the end of this appendix) shows several bank-protection projects incorporating large woody debris into them.

Large woody debris should not be placed during emergency conditions or for the purpose of alleviating emergency problems. Large woody debris can only be anchored or placed effectively in relatively calm and/or dewatered environments.

Large Woody Debris for Catching Debris

It is generally accepted that the more wood found in a given reach, the better the habitat. Large woody debris, used as mitigation, should be installed as dense clusters or have the capability of recruiting other debris from the stream. Single logs provide little habitat by themselves; and, as time passes, even isolated rootwads become featureless stumps providing little cover.

Wood recruitment is the stream's habitat-revitalizing force, adding complexity and renewing cover over time. Streambank-protection techniques made of rock are not effective at recruiting wood on their own, so large woody debris should be incorporated into them; large woody debris tends to collect other debris, encouraging the recruitment of even more wood. For wood recruitment to occur properly, logs with rootwads should be positioned so that a portion of the rootwads is above the flood-flow water surface. Floods make large woody debris available as they erode banks, drawing large and small trees into the active channel. Small trees and wood material added to the channel float downstream and are often captured by existing downstream log jams. If logs with rootwads are installed alone and low on rock revetments, they will not collect this liberated debris as it floats by. The ideal solution is to have wood at various elevations on the bank to ensure recruitment at all flows.

In systems with high banks and infrequent out-of-bank flows, the wood stays along the thalweg in the deeper, faster moving water and does not tend to accumulate along the banks. In order to recruit debris, large wood in rock-treated banks must stick out into the flow and be high enough to capture floating debris. Wood tends to accumulate at the downstream end of a bend as momentum resists making the final turn. This is a good place to expect logs to rack up on placed large woody debris.

Large Woody Debris in Rock Toes or Revetments

Engineered log jams provide immediate, stable habitat and bank protection. Log jams that have been installed in front of rock toes or revetments as mitigation have provided some habitat value. With the effective use of wood in streambank protection on the rise, it is wise to consider using wood instead of rock if at all possible. Trees with rootwads are the best material to use.

Rock for bank-protection projects is frequently sized according to a minimum stable dimension or gradation. These stability equations and tables are for smooth banks with flow running on an alignment parallel to the bank. When wood is added to the revetment design, failure may result from turbulence or redirected flow unanticipated in the original rock-sizing criteria. The designer must account for these hydraulic forces in stone sizing and the determination of stone layer thickness. Experience suggests that it is best to use the largest rock available for rock revetments, toes, groins and barbs that incorporate large woody debris. Refer to the discussion about *Riprap* in Chapter 6, *Techniques* for rock sizing information. While it may save money to opt for the minimum stable rock size for a particular project, the increase in risk may be unacceptable when also using wood. During floods, wood buoyancy and upstream wood collection cause shifts in hydraulic forces; and, together with impacts from large, floating logs, can quickly make even the largest rock inadequate to hold smaller-sized wood in place. A good understanding of the worst-case flood forces that could occur at the project site enables a design that will be long-lived and emulate the size of material that would naturally occur at each site.

The use of such large rocks and logs necessitates layered bedding, especially in fine-sediment banks and streambeds. Successful projects use progressively finer granular layers between the rock and the native bank material. Fine-grained soils may require small-diameter crushed rock or screened sand and gravel, followed by quarry spalls and light, loose riprap. Refer to the discussion about subsurface drainage in Chapter 6 for more information regarding selection of filter materials between riprap and native materials. Another approach is to use a well-graded pit run to provide the filter layer behind the riprap.

Based on a review of recent riprap revetment projects with large woody debris, two techniques show the most promise for stability and habitat:

- On an outside bend, large logs are embedded in a boulder toe, with rootwads extending in the channel. The logs are 30 feet long, embedded 15 feet into the bank and ballasted. The upstream angle can be from 30 to 50 degrees. Other logs can be attached to them. The log is placed at bed level. In confined streams with deep flood flow, additional logs are placed higher to collect debris.
- Log jams are constructed off the rock face to avoid jeopardizing rock placements and bank protection.

Large Woody Debris in Groins and Barbs

Large woody debris is used in groins in about the same way it is used in rock toes and revetments. However, there are a few added complications. Large logs with intact, finely branched rootwads are preferred for use in groins. They should be placed at bed level for cover purposes and also at higher stages to encourage recruitment. Logs need to be well embedded in the structure, placing one-half to two-thirds of the lower part of the tree trunk in the rock. The rock size should be increased to act as ballast; unless, as has been recommended, the largest rock available is already specified.

The positioning of large woody debris in the structure is the subject of some debate. It depends, in part, upon whether the structure is a barb or a groin. Barbs are positioned low and produce less scour and turbulence. As a result, sediment tends to accumulate around them and a new bankline develops. If large woody debris is placed near the bank upstream or downstream of a barb, it is likely to be in a deposition zone, and its value as cover is reduced or eliminated. To enhance fish habitat, it is useful to place large woody debris near the tip of barbs; however, designers have expressed concerns that this is the area of highest stress, and large woody debris may destabilize the structure and reduce its effectiveness as bank protection. This concern applies primarily to high-energy environments. Using wood on the end of a barb could cause problems if it collects additional wood and allows hydraulic scour to be focused on the bank the barb is designed to protect. Large woody debris, if placed near the tip, should be positioned low in the water column to provide cover, while reducing its ability to collect debris. A good understanding of the watershed wood transport/supply, hydrology, hydraulics and geomorphology are important. If the structure is properly designed, large woody debris will stay in it and improve habitat. Risk analysis and design requirements will help determine the applicability of wood in barbs at a given site.

In contrast to barbs, groins are high structures that trigger more pronounced turbulence and scour. As a result, the area near the bank may stay scoured, and large woody debris located here can provide good cover and complexity. Wood can also be placed near the tip on the upstream face of groins. There is usually more rock in groins than in barbs, so wood can be positioned more securely in groins than in barbs.

ANCHORING CONSIDERATIONS

Successful projects have used many types and methods of anchoring. Personal preferences and site conditions govern which types and methods are used. Wood placed in groups with multiple, fixed anchoring points will tend to be more stable than single pieces with one anchoring point. Structures made of single or multiple pieces of large woody debris, boulders and other materials are commonly used in streams and rivers as habitat features, fish-passage structures and bed- and channel-stabilization features.

The design of anchoring systems should consider the balance of forces between structure buoyancy and weight, and between drag forces and frictional resisting forces. The drag and friction calculations are prone to error, largely due to the unpredictable potential for a structure to collect additional debris. Partially buried logs extending into the current are often subjected to substantial oscillation and vibration. These movements can weaken a structure. The difficulty in predicting forces on structures in a river leads to the need for a substantial factor of safety in anchoring design. A minimum safety factor of 2.0 is recommended.

Types of Anchors

There are three common ways of anchoring materials in a river:

1. holding the feature rigidly in place using ballast;
2. tethering the structure so there is some degree of movement flexibility with varying flows; and
3. using passive anchoring, where the weight and shape of the structure is the anchor, and movement at some flow level is acceptable.

Rigid Anchors

Rigid anchoring is usually desired where long-term grade control or direct bank protection is the objective. Some structures that are embedded in the bank can lead to continued bank failure if they shift or move downstream.. Due to the anticipated permanence of this approach, it is important that the structure being anchored is properly designed and positioned. The anchoring methods most commonly used include ballast (cabling or pinning), a deadman, bedrock, and piled or standing trees. Rigid anchoring can also be accomplished by direct burial of part of the structure. Woody debris embedded in a barb, groin, rock toe and revetment are examples of rigid-anchor structures.

Flexible Anchors

Flexible (tether) anchors use materials that are similar to those used in rigid anchors; however, in this case, tethers allow the large woody debris structure to shift with changing flow stage or direction. Tethers are appropriate where the structure is providing roughness or cover and where exact positioning of the feature is not critical. Such an approach is intended to provide a base for other debris to collect and stabilize in one location. The tether must be designed to prevent the structure from moving near the bank. One desirable outcome of using such structures is the creation of local scour. Tethered structures move with the current, scouring or "mining" everywhere they move. Secure tethering requires that anchors be attached at several points on the structure.

Tethered structures float and allow flood flows to pass under them, presumably reducing stress on the structure.[2] However, flexible anchoring introduces dynamic forces that add stress to the anchoring system. Structures are often tethered to points both on the bank and in the channel. Tethered anchors should not be used in high-energy stream channels.

Passive Anchors

Passive anchors use the weight and shape of a structure itself to provide resistance to movement. Log jams can be anchored by large debris pieces (whose own weight will stabilize them), rootwads, and frictional resistance of the buried bole.[3] Bracing one or both ends of a log against trees or bedrock is also a form of passive anchoring. Individual boulders can be placed within a woody-debris matrix without cabling because they provide additional weight for structural stability. A debris structure can be considered passively anchored as long as they are cabled or pinned in a rigid matrix but remain unattached to any exterior anchors. The structure may become mobile at high flows, but the size and shape of the structure keeps it from moving a great distance. This may be a preferred approach for some habitat-mitigation structures. If cable is used, it should be galvanized and have a steel core. Half-inch cable has been used successfully in upper, fifth-order streams within high-energy, rain-on-snow flood environments. Just as boulders should be properly sized, so should cables. Cable smaller than one-half inch in diameter is not appropriate.

METHODS OF ANCHORING

Cabling or Chaining

This method includes attachment with various materials including cable, wire rope, chain, rope and straps. Where a permanent, rigid anchor is desired, cable (wire rope) and chain are appropriate choices. If temporary anchoring is the goal, the use of hemp or other biodegradable, natural-fiber rope or strap may be the solution. Rope or straps of synthetic material may have a life expectancy somewhere between cable and biodegradable ropes.

Cable is available in galvanized and nongalvanized forms. Galvanized cable has the advantage of being resistant to corrosion but should still be cleaned prior to being used with adhesives such as epoxy. Cable can be cut in the field using guillotine-type cutters (which tend to leave a frayed end that can be difficult to insert into holes) or by using a skill saw with a metal cutting blade (which makes a cleaner cut). The best way to cut cable in the field is with a hydraulic shear, which can be carried in a backpack and weighs approximately 15 pounds.

Cables are typically connected to each other and to anchors and woody debris using cable clamps. *Cable clamps* (clips) are a weak point in cable anchors. Using safety factors of two to three times the estimated loading is prudent in the dynamic environment of streams. Improperly placed clips can reduce the efficiency of the connection up to 40 percent of the cable strength. Thus, it is important to pay careful attention to this aspect of anchor design and construction. Clip efficiency is affected by orientation, tightening, spacing and the number of clips used.[4] The minimum number of clips ranges from two clips for 3/8-inch-diameter cable to five clips for one-inch diameter cable. Standard wire rope clips on a thimble eye obtain up to 80 percent of the strength of the rope when properly made. Specialty hardware can form eye loops with up to 100 percent of the rope strength. Flemish loops (a hand-formed loop) only develop up to 70 percent of the strength of the wire rope.

When attaching cable to logs, always remove the bark from the area enclosed by the cable. Otherwise, the cable will loosen as the bark rots. To prevent the cable from slipping along the log, insert the cable through a drilled hole in the log or create a notch around the log using a chainsaw or axe. If rigid anchoring is required, a winch or other equipment is necessary to tension the cable properly before tightening the attachment hardware. Key wood placements should be oriented perpendicular to each other. Following cabling, any wood movement should not be able to create slack in the cable. Staples can be used in addition to cable clamps (in some cases, instead of cable clamps) to secure cables to large woody debris. When installing staples, avoid excessive crimping of the cable.

Pinning

Steel pins have been used successfully to connect individual pieces of large woody debris, to attach large woody debris to other anchors and to serve as direct anchors (by being driven into the substrate). Wooden dowels have also been suggested for pinning, but no known applications are in place.

The main concerns associated with pinning include adequate strength, durability of materials and security of attachment. Determining forces on large woody debris in rivers is challenging, so using conservative factors of safety in design is recommended. Durability of steel pins depends upon the corrosive or electrolytic nature of the soils and water, which may greatly reduce longevity at some locations.

Pin-attachment effectiveness depends upon the materials used. Threaded rods or rebar are the most common materials used. Rebar pinning relies on shaft friction to maintain attachment. Using a cable clamp at one or both ends or bending the protruding rebar end reduces the chance of pullout. When using threaded rods or bolts as connectors, large washers should always be used. Pilot holes are necessary for driving pins through large logs, and special, extended-shaft auger bits must be made for drilling through stacked logs.

Angle iron plates with four holes on each end for spikes have been used successfully in high-energy environments. These should be used to supplement cable in debris jams within higher-energy environments. Half-inch lag bolts or spikes at least six to eight inches long should be used.

Pieces of debris have also been anchored using various lengths of rebar driven into the streambed or bank. The rebar is driven through a pilot hole in the debris and into the streambed using a fence-post driver, sledgehammer or vibrator hammer with a special adapter for the rebar. These applications have had variable success due to difficulty in driving the rebar to adequate depth and the varying ability of subsoil to secure the driven rebar. For this reason, this method is not recommended as the sole method of anchoring treatments requiring long-term, rigid anchors.

Deadman Anchors

A deadman is a common form of anchor using a wide array of potential materials. The concept of a deadman is to bury an anchor in the bed or bank. The anchor pushes against a wedge of undisturbed soil when tensioned. One advantage of a deadman anchor is that it can be placed in the bank away from the potential erosion zone, keeping heavy equipment out of the stream. A structure usually requires at least two deadman anchors or a combination of a deadman and other anchors. A single deadman might be used as a tether anchor.

Commercial anchors are available that can be driven or screwed into the soil. The driven style is set by providing tension on the anchor. The tension causes the deployment of legs or plates, which actually provide the anchorage. These anchors depend entirely on the shear strength of the soil and, therefore, are not acceptable in unconsolidated gravel beds.

Buried boulders, logs, concrete blocks or steel shapes are also used as deadman anchors. They have the advantage of their weight adding ballast, and they have more bearing area than commercial anchors. In the application of ecology blocks as deadman anchors, the anchor tie should be cable- or chain-wrapped around the block, not through the lifting eye on the block.

Designing deadman anchors requires information on soil characteristics. The strength and tightness of soil will determine the style and number of anchors required. In design, a simple pull-out analysis should be completed to determine the appropriate depth and style of anchor for a particular application. In addition, the manufacturer's specifications should always be followed for commercial anchor systems.

The movement of anchored debris can cause the anchoring cable or chain to slice through and loosen the soil lying between the anchor and the debris. When this occurs, the soil becomes more susceptible to erosion. For this reason, deadman anchoring systems should be designed such that they minimize the range of movement of a piece of anchored debris. Multiple, strategically located anchors will typically restrict woody debris movement more effectively than a single anchor. If movement of the woody debris is desired, an alternative anchoring system, such as ballast or pilings, should be considered.

Anchoring to Bedrock and Boulders

When structures are to be placed on or near bedrock or anchored to boulders, the rock can be drilled and anchors set into it. The bedrock or boulders must be suitable and durable. The rock should be free from segregation, seams, cracks and other defects tending to destroy its resistance to weathering. Attachment to the bedrock or boulders can be accomplished by inserting cable, rebar, threaded rod or rock bolt anchors into a hole filled with the appropriate grout or adhesive as required by the manufacturer. Oiled cable must be carefully cleaned with acetone or muratic acid to allow bonding with the adhesive. The drilled hole must reach into unfractured rock to develop full anchor strength, and it must be of a depth and diameter as specified by the manufacturer. There are many types of anchor adhesives on the market. The type selected should take into account wet conditions, possible oversized holes, etc.

The following are steps recommended by typical product literature for attaching threaded rod or rebar to bedrock or boulders using an epoxy adhesive (similar techniques can be used for rock bolt anchors:

1. drill anchor hole typically 1/16 inch larger in diameter than the rod or 1/8 inch larger in diameter than the rebar. Cable has also been used as an insert, but some failures have been observed, probably due to the nonuniform surface relative to the drilled-hole alignment. If using cable, a better method would be to attach the cable to a rod or rebar;
2. clean the hole with a wire brush. Use air to blow out the hole to remove all dust and debris;
3. if the cable or steel rod is lubricated, clean the cable using acetone or muratic acid;
4. inject the adhesive into the hole per the manufacturer's specifications;
5. insert the rod or rebar, and turn it slowly until the end contacts the bottom of the hole (air pockets at the bottom of the hole reduce bonding strength);
6. make adjustments to the fastener before specified gel times; and
7. allow curing to occur (curing time is a function of temperature and varies from one to three hours).

Some adhesives may require dry surfaces for proper adhesion. Prior to using an adhesive, it's important to verify the conditions under which the adhesive functions most effectively and to make sure the product has not reached or exceeded its expiration date. Using adhesives that require dry surfaces should not be used on structures to be cabled instream.

If applied properly, some adhesives can hold to the point of cable failure.[5] While some systems provide adhesion under water, in practice they are difficult to apply in a flowing stream with consistent success. It is important to consider how wood will be cabled during the construction and placement. Failure to consider cabling during construction will reduce cabling effectiveness and structural integrity.

Another common anchoring method is to use threaded expansion anchors or rock bolts. There are a variety of commercial expansion anchors available. Advantages of rock bolts over glued-in cable or steel rod include faster installation time and achievement of full strength upon installation (no drying time necessary). A disadvantage of mechanical anchors is that they are more susceptible to vibration effects than glued anchors are. Another type of rock bolt anchor is the groutable, rebar type. This anchor is set and then pressure grouted to seal and fill all voids or cracks in the rocks. This type can be used in weaker rock.

Pilings

Where equipment access allows and soils are appropriate, structures can be anchored with piles. Piling materials include logs, wood timbers, steel beams or pipes. In streams with fine-grained bed material, logs can be sharpened on one end and driven into the bed with an excavator equipped with a thumb attachment. They can also be pushed horizontally into banks as long as soil composition is able to provide structure. Many streams have bed and bank material that is too large or compacted for this approach, and pile-driving equipment must be used. Pointed steel caps will aid in driving logs into a gravel/cobble bed. Steel beams or pipes can be used in the channel where the structure or bed material will cover the pilings. Pins or cables are used to attach materials to pilings. Logs can be wedged between pilings and held in place by water pressure. This approach has also been used successfully for building log jams. A web of cable between a series of pilings can also trap and hold woody debris, although boater-safety concerns preclude the use of this technique in most cases.

Typical piling anchor designs require one-half to two-thirds of the piling length be buried below the streambed surface. This is critical for structures where the pilings are located near or in the scour zone of the structure. Piling depth must be determined with consideration for the potential scour depths expected resulting from the design flood and forces acting on the piles. Additional pilings away from the scour zone may be required as they are in some designs of engineered log jams designs (see example drawings in the discussion about *Engineered Log Jams* in Chapter 6). A professional engineer should determine the structural requirements for anchorage using pilings.

Ballast

Any object that adds to the weight and frictional resistance of a structure is considered ballast. The most commonly used ballast material is rock. The rock (usually large boulders) is typically attached to the large woody debris using cables or chains, or by pinning. Concrete blocks can also be used; but, because they are unattractive, they are preferred in locations where they will remain out of sight. Another approach is to stack additional logs on top of a structure as ballast, with the logs that remain above the design flood elevation providing weight to the structure. The logs may either be attached or unattached to the structure. Since this type of structure may be higher than adjacent banks and can block a significant flow area of the channel, it may not be appropriate to use next to an unvegetated bank or high-risk area without additional bank protection.

Combinations of Anchoring Methods

Anchoring methods are often used in combinations suited to the particular task at hand. For instance, a constructed log jam may consist of logs pinned to each other and then cabled to boulder ballast. It is up to the designer to mix and match the anchoring techniques presented here (and any other feasible techniques) to produce an anchoring system for a specific project and situation. Creatively using large, standing trees, bedrock, boulders and sharp bends to passively anchor or establish large-wood accumulations are techniques used to create stable wood habitat that emulates natural habitat. The ability to visualize flood stage and response during construction at low flow is very helpful. Understanding the geomorphology, hydrology and hydraulics of the site during design enables one to better visualize flood stage and use what already exists on site to help construct a solid wood habitat project.

HABITAT CONSIDERATIONS

Once in the stream channel, large woody debris influences coarse-sediment storage, increases habitat diversity and complexity, retains gravel for spawning habitat, improves flow heterogeneity, provides long-term nutrient storage and substrate for aquatic invertebrates, moderates flow disturbances, increases retention of allochthonous (leaf litter) inputs, and provides refuge for aquatic organisms during a range of flow events.[6]

Wood, particularly smaller twigs, and leaves (which decay rapidly) provide a food source to some aquatic insects that fish consume. Large woody debris can capture smaller logs and fine, woody debris and retain it better than riprap can. Using only large wood to stabilize banks is a relatively new technology emulating the process of self-stabilization observed when large trees fall into rivers after being undercut. There have been several successful projects using only wood to stabilize banks. As with all tools, using wood to stabilize streambanks does not work in every location. Refer to the discussion about *Roughness Trees* in Chapter 6 for more detail about using wood in bank-protection projects.

Enhancement of fish-habitat features is also a benefit; it improves structural and hydraulic diversity, thereby providing habitat for a multitude of life stages and species of fish. Woody debris is an important component of juvenile salmonid habitat in larger rivers during spring, summer and winter. Habitat and fish-population surveys have demonstrated increased densities in areas with large woody debris. Coho salmon densities were positively related to increasing large woody debris surface areas in the main stem of Washington State's Clearwater River[7] and Skagit River.[8] It has also been demonstrated that chinook salmon tend to cluster near brush or large woody debris cover.[9] Fish densities are positively correlated with the increased surface area provided by large woody debris.[1]

A bibliography of literature addressing the role of wood in aquatic systems and riparian areas has been assembled by researchers in the United States, United Kingdom and Russia. It is available on-line at http://riverwood.orst.edu/html/intro.html.

RISK

Risks inherent in the use of woody debris include:

- boater safety;
- structural damage to the stone revetment, barb, etc. (if embedded in these structures), due to turbulence and concentrated flow caused by the large woody debris' placement in the structure and its orientation to the approach flow;
- structural damage to the stone revetment, barb, etc., due to the levering out of embedded large woody debris by flood flows, or the pull-out of deadman anchors;
- opportunity for cables and anchors to come loose within the channel, creating hazards for recreational users;
- blockage of culverts or bridge openings by large woody debris that has come loose and migrated from its point of installation; and
- a major change in channel direction and depth and can create a bifurcated or braided channels.

All of these risks can be minimized by exercising care in designing the placement of large woody debris.

ACQUISITION OF LARGE WOODY DEBRIS

Larger wood pieces are used for bank protection and the creation of log jams to create stable structures that emulate historic channel processes. Wherever possible, large woody debris should be used with intact rootwads. Obtaining, transporting and placing this wood is becoming increasingly difficult. Moderate-sized pieces can be obtained from timber companies or developers and transported in a trash hauler. Key pieces, appropriate for larger rivers, can be transported whole or in pieces on large flatbed trailers. Large wood cut for transport can be glued, cabled and/or bolted at the site to recreate original dimensions. Largeness is important; so, if only smaller pieces are available, then largeness and complexity should be emulated by binding them together.

Large woody debris should be of a size (length and width) and species to remain intact and stable for many years. Avoid using hardwood species such as alder or cottonwood, which decay rapidly; coniferous species such as cedar, fir and pine are better choices. Large-diameter and/or long logs, imported from off-site, may need to be cut into pieces for transport and then reassembled on site by splicing, gluing and tacking the pieces back together. Use of on-site wood resources can greatly simplify construction and reduce costs.

When standard equipment has not been able to move wood of the required size and length to the work site, helicopters have been used successfully to fly in whole trees weighing as much as 25,000 pounds from adjacent, upland blow-down locations and staging areas.

Wood is intended to remain submerged or partially submerged, so wood buoyancy can pose a problem during installation. To address this problem, the site may need to be dewatered to allow for placement and anchoring of large pieces. The use of wood that has already been saturated with water can simplify construction by reducing buoyancy problems during installation. Logs may need to have ballast attached before placement if the site cannot be adequately dewatered.

Turbidity will be a significant problem during installation due to the amount of digging in the channel bed that is required for installation. This can be addressed by dewatering the installation site, or by creating a coffer system that isolates the immediate site from flowing water.

Protection of the existing riparian zone should be a high priority, particularly in drier climates where replacement of the canopy can take decades. The use of walking excavators, winches and hand labor may be required at some sites.

As with any in-channel enhancement project, construction should be conducted during a period where the potential impacts to aquatic resources are minimal. Low-flow conditions are preferable for the placement of large woody debris jams. Instream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix B, *Washington Department of Fish and Wildlife Contact Information*). Further discussion of construction and dewatering can also be found in Appendix M, *Construction Considerations.*

MONITORING AND MAINTENANCE

Monitoring should be conducted during or following high-water events (i.e., floods). At a minimum, large woody debris placements should be monitored during and/or after two-year flow events for a minimum of five years following project completion to ensure the integrity of the anchors. If individual pieces have moved or become loose, they should be re-anchored. If large woody debris has been lost, the structure should be evaluated to decide if replacement is warranted. Replacement may depend upon potential damage to the recovering vegetation, as well as potential future damage to the bank if no repairs occur.

Objectives of monitoring include:

- evaluating the structural integrity of installed structures;
- evaluating structures relative to objectives of bank protection and fish habitat;
- measuring and surveying (topographically and photographically) any changes to banks and bed of stream; and
- measuring hydraulic and hydrologic impacts of the project.

For a comprehensive review of habitat-monitoring protocols, refer to Johnson, et al.[10] Habitat-monitoring protocols will likely require a monitoring schedule that is more comprehensive than that required for the integrity of the structure.

Maintenance needs are greatly reduced if large woody debris is engineered and installed properly. Maintenance may include securing damaged or degraded anchoring systems for the life of the project and removing nonwood components (cable) when structures fail or exceed their project life.

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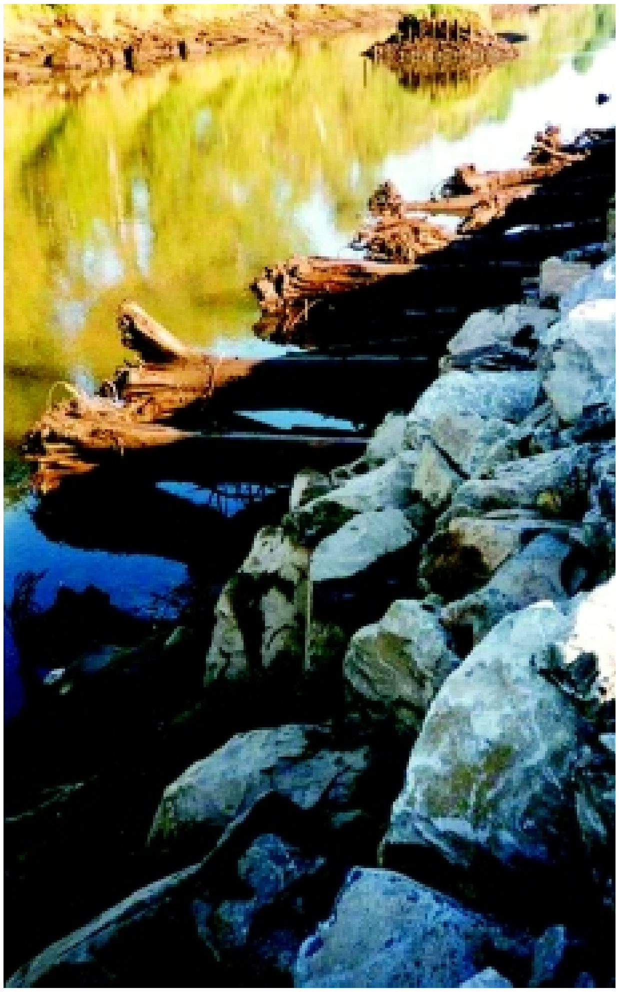

a. Large Woody Debris embedded in Rock Toe. Green River.
Source: King County Department of Natural Resources.

b. Large Woody Debris embedded and collected on Groin. Hoh River. 1998.

c. Large Woody Debris embedded in Rock Toe. Salmon Creek, Tributary to Columbia River.
Source: Inter-Fluve, Inc.

d. Large Woody Debris embedded in Groins. Big Quilcene River. 1997.

e. Large Woody Debris embedded in Groin. South Fork, Nooksack River. 2002.

Figure I-1. Large woody debris used in conjunction with various treatments.